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US Army Research Laboratory

Preliminary Comparison of March–May Radiosonde Soundings with March–May Climatological Profiles for Yuma, Arizona

by J Cogan and P Haines

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Computational Information and Sciences Directorate, ARL

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14. ABSTRACT
Climatological data are sometimes used in place of actual sounding data for planning and in field tests when sounding data are not available. However, the use of climate mean profiles may lead to wide differences from actual individual atmospheric profiles. This brief report investigates the variation of a series of soundings as compared to climate mean soundings and soundings computed from the sum of the mean ±1 or 2 climate-based standard deviations. Sounding data for Yuma Proving Ground (YPG), Arizona, from March to May 2016 were compared with climate data from March to May from 1987–2016 for YPG. As expected, there was wide variation in the individual profiles that sometimes led to large differences from the climate mean and occasionally exceeded or were less than the climate mean ±2 standard deviations, respectively.

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1. Introduction

Climatological data are sometimes used in place of actual sounding data for planning and in field tests when sounding data are not available. However, the use of climate mean profiles may lead to wide differences from actual individual atmospheric profiles. The US Army Research, Development and Engineering Center (ARDEC) asked for assistance in understanding the potential issues involved with the use of climate-based meteorological (MET) profiles during test events. This brief report investigates the variation of a series of soundings as compared to climate mean soundings and soundings computed from the sum of the mean ±1 or 2 climate-based standard deviations (SDs). Sounding data for Yuma Proving Ground (YPG), Arizona, from March to May 2016 were compared with climate data from March to May from 1987–2016 for the same site. As expected, there was wide variation in the individual profiles that sometimes led to large differences from the climate mean and occasionally deviated from the climate mean by more than 2 SDs.

2. Analysis

2.1 Procedure

A total of 40 computer MET messages (METCMs) derived from radiosonde observation soundings (RAOBs) were provided to the US Army Research Laboratory by the Meteorological Support Team at YPG for a period from March to May 2016. The maximum zone for those METCMs was 26, that is, the zone covering 19–20 km (midpoint 19,500 m) above ground level. The sample size for each zone, or line, is the number of populated lines, with a maximum of 40, with a lesser number at higher zones since some RAOBs ended at lower heights. Those METCMs were converted into ballistic meteorological messages (METB3s) using a modified version of software developed for a handheld device (Cogan and Sauter 2013). Information on the METCM and METB3 format and structure may be found in STANAG 4082 (2000) and STANAG 4061 (2000), respectively, as well as FM 3-09.15/MCWP 3-16.5 (2007). Those messages were compared with a METCM and METB3 derived from climate information provided by the US Air Force 14th Weather Squadron for the same site at YPG generated using data gathered from March to May from 1987–2016. As with the RAOB data, the single METCM from the climate data was converted into a METB3. In that way, the same procedure was used for both sets of data rather than a direct generation of a METB3 from the climatological profiles.

Spreadsheets were prepared in a manner similar to those used in a previous analysis (Cogan 2015). Here METCMs and METB3s for all RAOBs were compared with the single climate-based METCM and METB3, respectively. Overall mean, mean absolute error (MAE), SD, and root mean square error (RMSE) were computed for the differences between the climate- and sounding-based METCM and METB3 variables (climate – sounding) for each of the respective zones. Each sample is the difference value for one zone of each pair of RAOB- and climate-based messages, provided RAOB-based data were available. Consequently, the maximum sample size was 40, which progressively decreased at the highest zones due to some RAOBs ending at lower heights. The variables examined were based on the needs expressed by ARDEC. As a result, this analysis focused on differences in the METCM variables of pressure, virtual temperature, wind speed, and wind direction and on the METB3 variables of temperature, density, wind speed, and wind direction. Since a METB3 was derived from the respective METCM, the METB3 sensible temperature was replaced by virtual temperature. Where the atmosphere is dry in terms of absolute humidity, the difference between sensible and virtual temperature is small and could be ignored for this study. Dry, in this respect, normally occurs in dry climates such as in deserts and at higher altitudes. Also, the METB3 wind direction was in tens of mils versus the hundreds of mils of the standard format. The retention of the better precision of the METCM led to more precise statistics for the MET error budget calculations. Also, all RAOBs, including those used for the climate profiles that were derived from an extensive set of RAOB data, are only approximations of the actual atmosphere due to, for example, drift of the radiosonde and deviations from the listed launch time (e.g., Seidel et al. [2011]).

In addition to the usual METCM and METB3 variables, we also examined the differences in the vector wind speed (VW). For the RAOB data, VW was computed from the METCM or METB3 values of wind speed and direction for each zone. For the climate data supplied by the Air Force's 14th Weather Squadron, it may be computed directly from the listed horizontal wind components or from the wind speeds and directions of the respective METCM as was done for this report. The VW difference (ΔVW) is the magnitude of the 2 wind difference vectors and is computed as

$$(\Delta\mathrm{VW}) = \sqrt{(\Delta u)^2 + (\Delta v)^2}, \tag{1}$$

where Δu is the difference in the east–west (u) components and Δv is the difference in the north–south (v) components.

2.2 Results

Tables 1 and 2 contain the METCM statistical quantities of the 4 variables at each individual zone for all zones for all soundings and they include the sample size. The decrease of the sample size at higher zones is due to some RAOBs ending or producing incomplete data before reaching those higher zones. Table 3 has the statistical quantities for VW, computed using the respective METCM wind speeds and directions, for each individual zone for all zones for all soundings and includes the sample size.

Table 1 Statistical quantities for virtual temperature difference (K*10) and pressure difference (hPa) by zone for as many as all 40 cases with respect to the differences from the climate values. Comparisons were made up to the maximum METCM zone covered by each RAOB.

			Virtual Temperature Difference (K*10)					Pressure Difference (hPa)			
Samples	Zone		Mean	MAE	SD	RMSE		Mean	MAE	SD	RMSE
40	0		-16.4	59.4	68.0	69.1		0.3	2.4	3.0	3.0
40	1		2.6	53.8	63.0	62.2		0.7	2.2	2.8	2.8
40	2		12.4	51.9	61.4	61.9		0.6	2.1	2.6	2.6
40	3		18.6	52.3	60.0	62.1		0.7	2.0	2.6	2.7
40	4		24.1	52.4	58.6	62.6		-1.2	3.0	3.4	3.6
40	5		30.0	54.2	58.6	65.1		0.1	3.2	3.8	3.7
40	6		37.1	52.9	55.6	66.3		0.2	3.4	4.1	4.0
40	7		38.4	46.9	50.6	63.0		1.0	4.0	4.5	4.5
40	8		37.7	45.0	50.4	62.5		1.4	4.5	4.9	5.0
40	9		32.4	41.7	48.3	57.6		1.6	4.8	5.2	5.4
40	10		27.9	41.0	48.8	55.7		1.8	4.9	5.3	5.5
40	11		26.6	41.4	50.8	56.8		2.0	5.1	5.6	5.9
40	12		23.4	39.9	50.9	55.5		2.2	5.2	5.8	6.1
40	13		20.2	36.2	46.8	50.5		2.5	5.2	6.1	6.5
40	14		15.0	28.0	35.3	38.0		2.5	5.0	6.0	6.4
40	15		6.6	17.9	24.8	25.3		2.2	4.8	5.8	6.1
40	16		-2.1	14.5	18.3	18.2		2.7	4.4	5.1	5.7
37	17		-16.3	25.3	28.1	32.1		1.9	3.9	4.5	4.8
37	18		-21.6	37.8	45.9	50.1		1.2	3.3	3.7	3.8
37	19		-18.9	43.1	51.0	53.7		1.0	2.8	2.9	3.1
35	20		-19.5	32.4	36.5	40.9		0.7	2.2	2.2	2.3
34	21		-13.6	18.8	21.6	25.3		0.3	1.7	1.8	1.8
27	22		-10.9	15.8	17.0	20.0		-0.6	1.3	1.4	1.5
18	23		-9.6	16.6	20.5	22.1		0.0	1.1	1.2	1.2
18	24		-7.5	12.1	11.9	13.8		-0.4	0.8	0.8	0.9
11	25		-15.9	17.9	15.6	21.8		-0.4	0.9	0.9	1.0
6	26		-12.3	15.7	13.5	17.5		0.0	0.3	0.6	0.6

Table 2 Statistical quantities for wind direction difference (tens of mils) and wind speed difference (kn) by zone for as many as all 40 cases with respect to the differences from the climate values. Comparisons were made up to the maximum METCM zone covered by each RAOB.

Samples	Zone	Wind Direction Difference (tens of mils)				Wind Speed Difference (kn)			
		Mean	MAE	SD	RMSE	Mean	MAE	SD	RMSE
40	0	30.7	79.0	98.1	101.6	0.3	2.9	3.4	3.4
40	1	35.0	76.5	95.7	100.8	0.3	2.8	3.5	3.5
40	2	31.5	72.6	86.6	91.2	0.3	3.8	4.6	4.6
40	3	25.1	77.9	88.6	91.0	0.7	3.7	4.6	4.6
40	4	-17.6	82.2	95.5	95.9	1.6	5.1	6.5	6.6
40	5	-67.1	104.7	112.0	129.3	1.8	6.0	7.2	7.4
40	6	-61.1	110.3	119.3	132.7	3.3	6.9	7.8	8.4
40	7	-87.8	106.6	97.8	130.6	3.5	8.3	9.2	9.8
40	8	-63.7	112.8	130.2	143.5	4.1	9.1	10.9	11.5
40	9	-69.8	88.5	98.1	119.4	3.0	10.7	14.4	14.5
40	10	-55.7	68.5	70.8	89.4	1.2	10.2	15.3	15.2
40	11	-49.6	67.4	76.0	90.0	0.9	10.1	16.1	15.9
40	12	-42.7	67.4	75.5	85.9	-1.0	11.1	18.8	18.6
40	13	-40.8	69.4	79.8	88.7	-2.2	13.9	21.5	21.4
40	14	-39.0	69.0	77.5	85.9	-6.3	16.9	24.0	24.5
40	15	-36.8	64.4	74.0	81.8	-9.0	20.6	26.1	27.3
40	16	-27.6	57.6	65.8	70.6	-6.3	21.8	28.0	28.4
37	17	-19.4	48.2	51.2	54.1	-4.0	23.9	32.3	32.1
37	18	-13.7	35.4	37.2	39.2	-7.2	24.2	37.7	37.9
37	19	-12.9	28.2	32.2	34.3	-3.3	20.6	28.5	28.3
35	20	-14.4	26.0	30.6	33.4	0.0	18.5	22.7	22.4
34	21	-12.6	21.6	24.2	26.9	0.8	17.3	21.0	20.7
27	22	-13.7	21.7	22.0	25.6	-3.5	12.1	14.6	14.7
18	23	-28.1	33.3	27.3	38.6	-4.5	6.4	7.4	8.5
18	24	-17.8	32.9	34.6	38.0	-2.0	8.0	10.5	10.4
11	25	-23.7	33.4	37.2	42.7	-2.2	6.2	7.3	7.3
6	26	-22.0	25.3	29.5	34.8	0.8	5.5	7.4	6.8

Table 3 Statistical quantities for VW difference (kn) by zone for as many as all 40 cases with respect to the differences from the climate values. Comparisons were made up to the maximum METCM zone covered by each RAOB.

		Vector Wind Speed Difference (kn)			
Samples	Zone	Mean	MAE	SD	RMSE
40	0	4.7	4.7	2.3	5.2
40	1	5.5	5.5	3.1	6.3
40	2	7.3	7.3	3.6	8.2
40	3	9.1	9.1	3.7	9.8
40	4	10.9	10.9	5.3	12.1
40	5	12.6	12.6	5.6	13.8
40	6	14.7	14.7	6.4	16.0
40	7	17.1	17.1	7.4	18.5
40	8	18.7	18.7	8.6	20.5
40	9	19.8	19.8	9.8	22.1
40	10	20.4	20.4	11.9	23.6
40	11	21.8	21.8	14.1	25.9
40	12	24.7	24.7	16.4	29.5
40	13	29.2	29.2	21.2	35.9
40	14	34.8	34.8	22.4	41.2
40	15	38.6	38.6	21.6	44.1
40	16	38.2	38.2	17.8	42.1
37	17	37.8	37.8	20.0	42.6
37	18	35.5	35.5	26.0	43.8
37	19	30.1	30.1	16.1	34.0
35	20	26.2	26.2	9.8	27.9
34	21	22.2	22.2	9.0	23.9
27	22	17.4	17.4	5.5	18.2
18	23	14.8	14.8	6.1	15.9
18	24	12.9	12.9	5.3	13.9
11	25	10.0	10.0	3.0	10.4
6	26	7.0	7.0	3.9	7.9

The data in Tables 1–3 are presented in graphical form as Figs. 1–3 to more clearly show the relations between the METCMs from the soundings and the climate-based METCM.

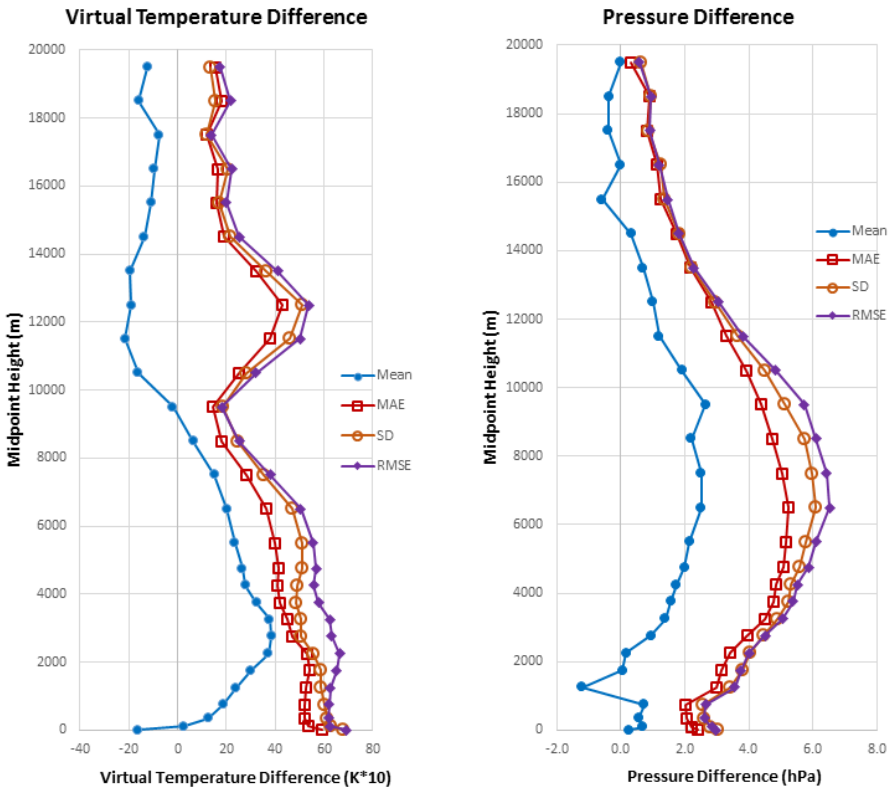

Fig. 1 Statistical quantities in graphical form for virtual temperature (K*10) and pressure (hPa) by zone for as many as all 40 cases with respect to the differences from the climate values. Comparisons were made up to the maximum METCM zone covered by each RAOB. This figure may be compared with Table 1.

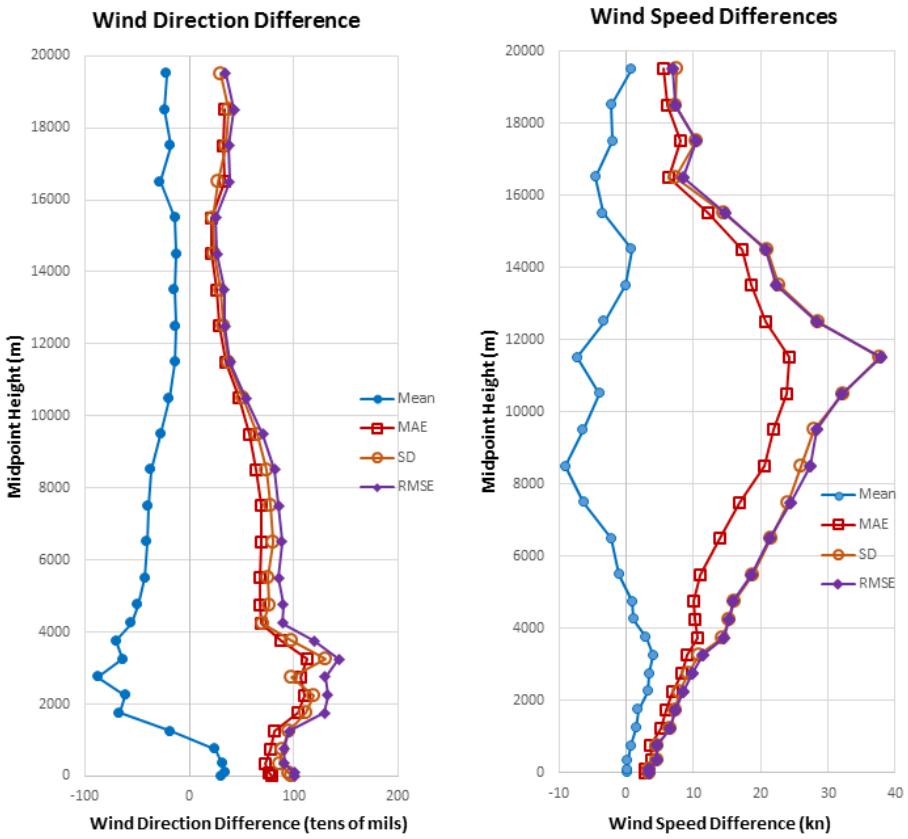

Fig. 2 Statistical quantities in graphical form for wind direction (tens of mils) and wind speed (kn) by zone for as many as all 40 cases with respect to the differences from the climate values. Comparisons were made up to the maximum METCM zone covered by each RAOB. This figure may be compared with Table 2.

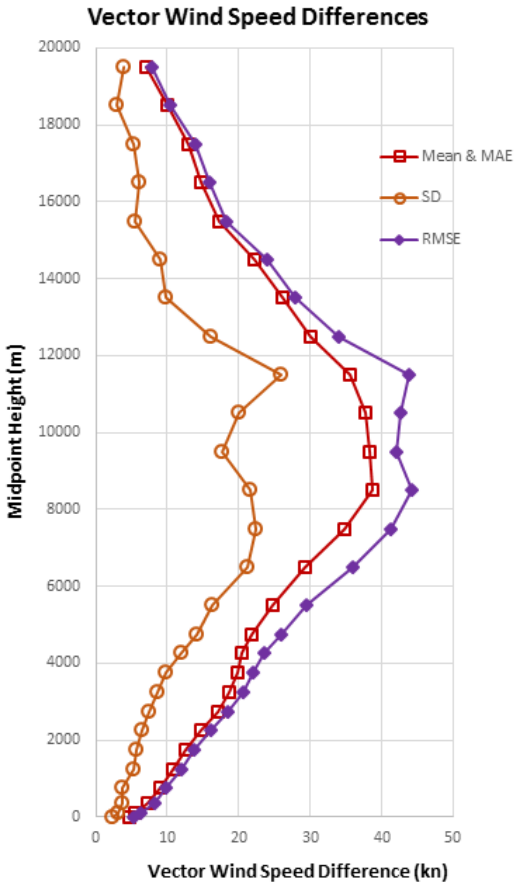

Fig. 3 Statistical quantities in graphical form for VW (kn) by zone for as many as all 40 cases with respect to the differences from the climate values. Comparisons were made up to the maximum METCM zone covered by each RAOB. This figure may be compared with Table 3.

Tables 4 and 5 contain the METB3 statistical quantities of the 4 variables at each individual zone for all zones for all soundings including the sample size. The decrease of the sample size for higher zones is due to some RAOBs ending or producing incomplete data before reaching those higher zones. The METB3 has density and virtual temperature units in percentage of standard times 10. Here standard refers to the same standard atmosphere used in the current MET error budget tables, which, in turn, is based on the International Civil Aviation Organization 1976 standard atmosphere. Table 6 has the statistical quantities for the VW, computed using the respective METB3 wind speeds and directions, for each individual zone for all zones for all soundings and includes the sample size.

Table 4 Statistical quantities for virtual temperature difference (%std * 10) and density difference (%std * 10) by zone for as many as all 40 cases with respect to the differences from the climate values. Comparisons were made up to the maximum METB3 zone covered by each RAOB.

Samples	Zone	Virtual Temperature Difference (%std*10)				Density Difference(%std*10)			
		Mean	MAE	SD	RMSE	Mean	MAE	SD	RMSE
40	0	-5.8	20.6	23.5	23.9	4.9	20.1	23.1	23.3
40	1	0.9	18.8	22.0	21.7	-0.9	18.4	21.7	21.4
40	2	3.6	18.3	21.5	21.6	-2.4	18.0	21.2	21.1
40	3	5.5	18.2	21.2	21.7	-3.9	17.2	20.3	20.4
40	4	7.5	18.5	20.9	22.0	-5.6	16.7	19.6	20.1
40	5	8.3	18.7	20.9	22.2	-6.9	16.5	19.1	20.0
40	6	11.3	18.1	19.9	22.6	-8.5	15.4	17.6	19.3
40	7	12.1	17.2	19.0	22.3	-9.4	13.9	15.9	18.3
40	8	11.4	16.2	18.5	21.6	-8.5	12.4	14.6	16.7
40	9	10.6	15.8	18.9	21.5	-8.5	11.6	13.5	15.8
40	10	10.6	15.8	18.9	21.5	-6.0	9.0	10.7	12.1
40	11	10.6	15.8	18.9	21.5	-4.3	5.8	6.5	7.7
37	12	11.1	16.8	19.6	22.3	-1.7	3.4	3.8	4.1
35	13	12.2	17.2	19.5	22.7	-1.8	3.3	3.3	3.7
27	14	10.1	16.5	20.8	22.8	-3.1	3.8	3.2	4.4
18	15	9.2	15.3	19.1	20.7	-3.7	3.9	2.7	4.5

Table 5 Statistical quantities for wind direction difference (tens of mils) and wind speed difference (kn) by zone for as many as all 40 cases with respect to the differences from the climate values. Comparisons were made up to the maximum METB3 zone covered by each RAOB.

Samples	Zone	Wind Direction Difference (tens of mils)				Wind Speed Difference (kn)			
		Mean	MAE	SD	RMSE	Mean	MAE	SD	RMSE
40	0	30.7	79.0	98.1	101.6	0.3	2.9	3.4	3.4
40	1	35.0	76.5	95.7	100.8	0.3	2.8	3.5	3.5
40	2	32.8	72.3	85.7	90.8	0.6	3.6	4.3	4.3
40	3	26.4	76.4	86.9	89.7	0.5	3.5	4.3	4.3
40	4	1.1	74.6	88.8	87.7	1.3	4.2	5.2	5.3
40	5	-21.6	77.4	90.6	92.1	1.9	5.3	6.2	6.4
40	6	-53.7	96.1	101.6	113.8	3.1	6.4	7.2	7.7
40	7	-55.7	85.8	92.9	107.3	3.8	8.1	9.7	10.3
40	8	-50.9	68.0	73.9	89.0	2.8	8.5	11.1	11.3
40	9	-46.5	66.7	74.5	87.0	1.3	8.6	12.8	12.7
40	10	-42.4	68.3	76.6	86.8	-0.6	11.4	16.9	16.7
40	11	-38.5	64.7	73.1	81.8	-2.7	11.9	17.7	17.7
37	12	-33.1	58.9	63.6	70.9	-1.9	14.7	21.9	21.7
35	13	-29.0	51.5	55.1	61.6	-0.6	15.0	21.1	20.8
27	14	-30.7	53.3	54.5	61.6	-3.4	15.2	20.8	20.7
18	15	-32.9	55.7	56.3	63.9	-8.0	14.7	19.8	20.9

Table 6 Statistical quantities for VW difference (kn) by zone for as many as all 40 cases with respect to the differences from the climate values. Comparisons were made up to the maximum METB3 zone covered by each RAOB.

Samples	Zone	Vector Wind Speed Difference (kn)			
		Mean	MAE	SD	RMSE
40	0	-4.7	4.7	2.3	5.2
40	1	-5.5	5.5	3.1	6.3
40	2	-7.1	7.1	3.5	7.9
40	3	-8.2	8.2	3.5	8.9
40	4	-9.2	9.2	4.1	10.1
40	5	-10.6	10.6	4.5	11.5
40	6	-12.9	12.9	5.5	14.0
40	7	-15.7	15.7	6.4	16.9
40	8	-16.9	16.9	7.9	18.6
40	9	-18.3	18.3	10.1	20.8
40	10	-24.5	24.5	15.6	28.9
40	11	-26.5	26.5	15.1	30.5
37	12	-28.2	28.2	14.6	31.7
35	13	-26.9	26.9	12.5	29.6
27	14	-27.2	27.2	10.9	29.2
18	15	-28.1	28.1	9.7	29.7

The climate data provided by the 14th Weather Squadron also included the SDs of many of the variables as well as the mean values. Using those data, we compared the sounding-based to the climate-based METCM mean profiles of wind speed, virtual temperature (T_v), and pressure; the profiles with +1 SD and +2 SDs; and the most extreme profile of those variables from the 40 METCMs based on the soundings. For T_v and pressure, the profiles with –1 SD and –2 SDs were compared as well. Wind speed is shown in Fig. 4 and has the most extreme difference from the climate-based METCM. The T_v changes are shown in Fig. 5, but given the smaller relative changes only the ±2 SD curves are presented. Figure 6 presents the same type of information as Fig. 5, but for pressure. Since the scales of the pressure chart (Fig. 5a) suggest only small differences between the profiles, a second chart (Fig. 5b) was prepared that contains the vertical section (5,500- to 9,500-m METCM midpoint heights) with the greatest profile differences on an expanded scale.

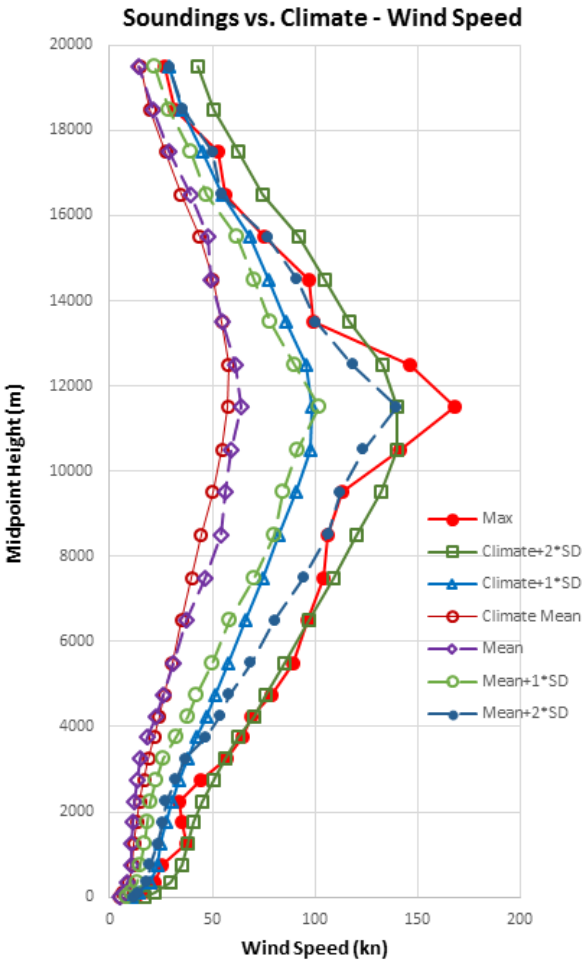

Fig. 4 The maximum METCM wind speed profile from the sounding data compared with the climate and sounding profiles of mean and mean + 1 SD and + 2 SDs

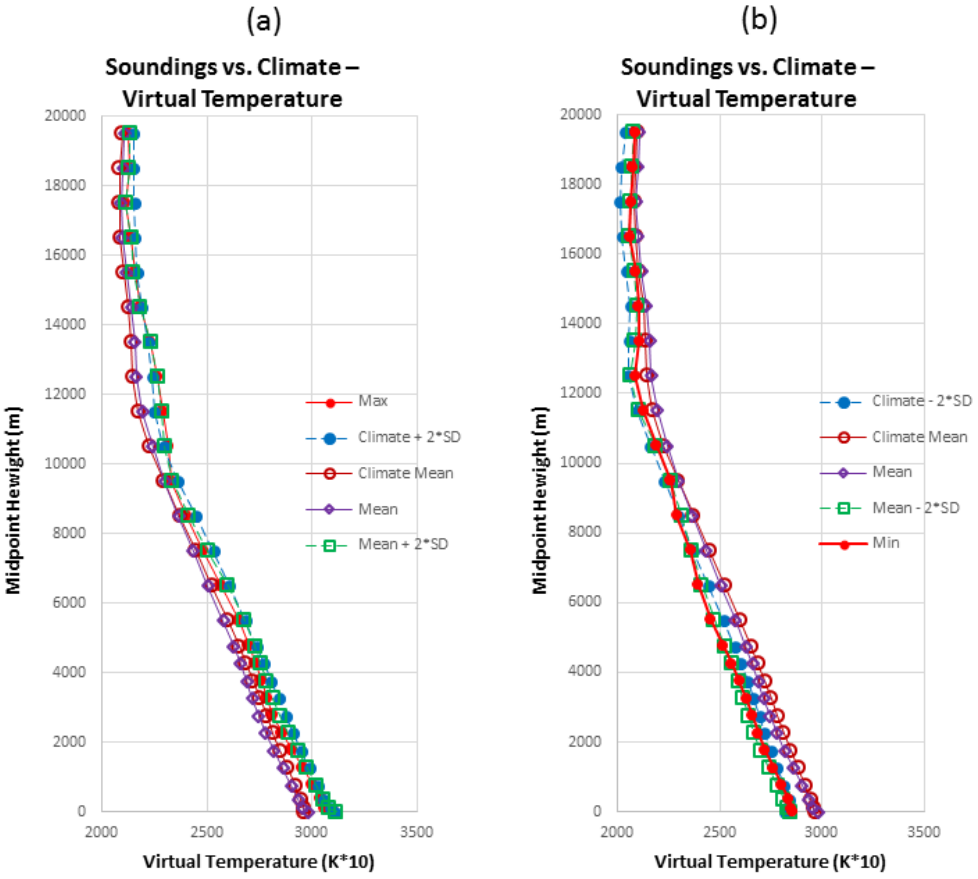

Fig. 5 The maximum a) and minimum b) METCM T_v profiles from the sounding data compared with the climate and sounding profiles of mean and mean a) + 2 SDs and b) – 2 SDs

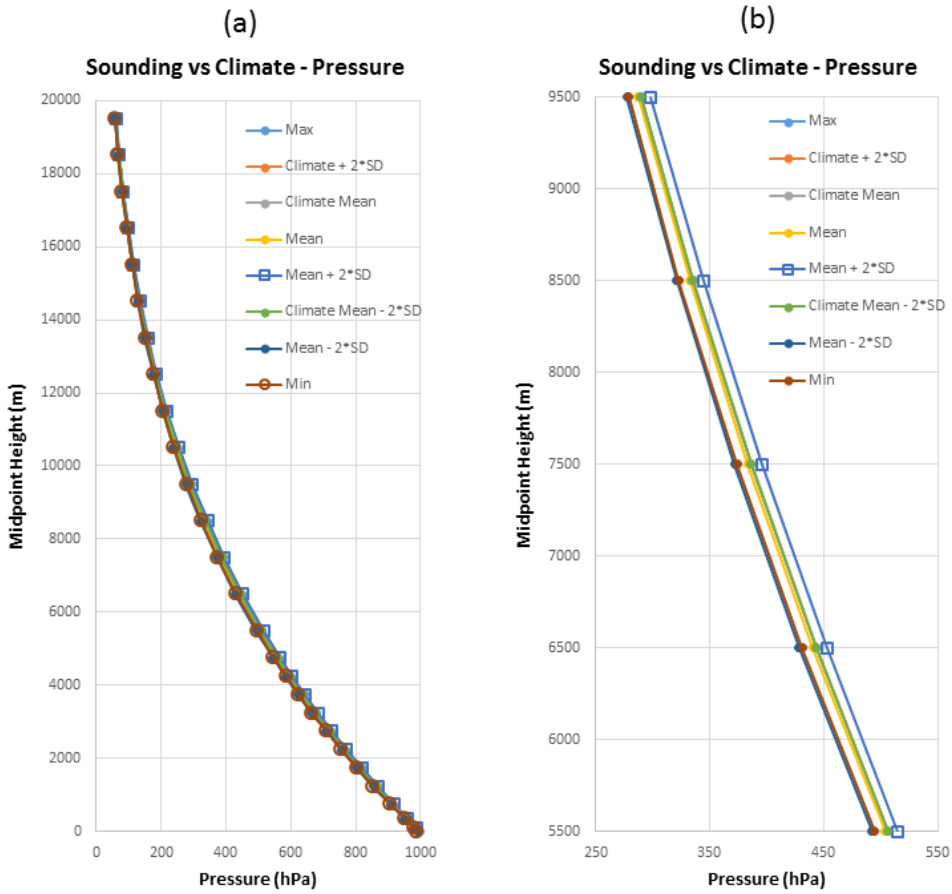

Fig. 6 The METCM maximum and mean pressure profiles from the sounding data compared with the climate and sounding profiles of mean and mean ± 2 SDs. The chart on the left (a) has the complete METCM profiles and the one on the right (b) has the section with the greatest differences. Note the different scales on the axes.

The mean and SD of wind speed of the METCMs derived from RAOBs from March to May 2016 and that derived from climate profiles for spring (March to May 1987–2016) are similar, especially the mean profiles (Fig. 4). The mean + 2 SDs profile from the soundings is less than that from the climate data. If climate data are used, the user needs to consider using mean + 2 SDs (or greater than +2 SDs) to include a high percentage of strong wind events. Overall, the maximum and minimum T_v values from the soundings fit within the mean ± 2 SDs (Fig. 5). The maximum pressures are less than the mean + 2 SDs, but the minimum pressures are about the same as the mean – 2 SDs though slightly less for some zones (Fig. 6a; zones 3–7).

If we assume a Gaussian distribution, with a very large sample the distribution below "mean + SD" covers about 84% of individual occurrences (i.e., ~16% of them exceed "mean + SD"), and below "mean + 2 SDs" covers about 98% (~2% exceed "mean + 2 SDs"). For T_v and pressure, assuming a Gaussian distribution even though this data set is fairly small, the same approximately holds for +1 SD

and +2 SDs. For –1 SD and –2 SDs, approximately 16% and approximately 2%, respectively, of individual occurrences have smaller values. For wind speed, a Gaussian distribution is not normally used since wind speed is never less than 0. The distributions frequently used for wind speed are the Weibull distribution and the Rayleigh distribution, which is a "special case" of the Weibull distribution. The document located at www.csun.edu/~lcaretto/me483/probability.doc contains definitions and other information on both distributions, as does Monahan et al. (2011). Calculations of the Rayleigh mean and SDs for the METCM suggested that the former is not far from the MAEs and the latter is not too far from the "Gaussian" SDs except around zones 16–20 (SD – SD[Rayleigh] > 5 kn with a maximum of 8.2 kn at zone 18). However, since the climate data file has normal distribution-based means and SDs, we used those for the comparisons herein. Further investigation, which is beyond the scope of this brief study, using a much larger sounding data set and climate-based values of the Rayleigh distribution parameters could lead to a more definitive comparison. Nevertheless, based on this data set, occasional values greater than the climate mean + 2 SDs (Gaussian) for wind speed, greater or lesser than ±2 SDs for T_v, and less than –2 SDs for pressure may be expected at YPG during the spring season.

The data for the METB3 also may be presented in a MET error budget format as in Table 7. Density and virtual temperature units are in percentage of standard, the same units as in the current MET error budget tables, versus percentage standard times 10. The current tables do not have wind direction, but have been included here at the request of potential users of the information. In addition, VW difference statistics are presented in Table 8 in the same form as Table 7. VW difference may provide a better metric versus wind speed difference, since it accounts for changes in wind direction as well as wind speed.

Table 7 METB3 results in the MET error budget format where the statistics shown compare the RAOB-derived METB3s to the single climate-based METB3

		Density (%std)				Wind Direction (tens of mils)				Wind Speed (kn)				Virtual Temperature (%std)			
Zone	Samples	Mean	MAE	SD	RMSE	Mean	MAE	SD	RMSE	Mean	MAE	SD	RMSE	Mean	MAE	SD	RMSE
0	40	0.49	2.01	2.31	2.33	30.70	79.00	98.12	101.63	0.25	2.85	3.39	3.36	-0.58	2.06	2.35	2.39
1	40	-0.09	1.84	2.17	2.14	34.98	76.48	95.72	100.78	0.30	2.75	3.51	3.48	0.09	1.88	2.20	2.17
2	40	-0.24	1.80	2.12	2.11	32.78	72.33	85.71	90.75	0.60	3.55	4.32	4.31	0.36	1.83	2.15	2.16
3	40	-0.39	1.72	2.03	2.04	26.38	76.43	86.86	89.74	0.50	3.50	4.33	4.31	0.55	1.82	2.12	2.17
4	40	-0.56	1.67	1.96	2.01	1.05	74.60	88.78	87.67	1.30	4.20	5.21	5.31	0.75	1.85	2.09	2.20
5	40	-0.69	1.65	1.91	2.00	-21.63	77.38	90.63	92.06	1.85	5.30	6.16	6.36	0.83	1.87	2.09	2.22
6	40	-0.85	1.54	1.76	1.93	-53.70	96.10	101.56	113.76	3.10	6.35	7.16	7.72	1.13	1.81	1.99	2.26
7	40	-0.94	1.39	1.59	1.83	-55.70	85.80	92.86	107.28	3.78	8.13	9.65	10.25	1.21	1.72	1.90	2.23
8	40	-0.85	1.24	1.46	1.67	-50.93	68.03	73.88	88.97	2.80	8.50	11.12	11.33	1.14	1.62	1.85	2.16
9	40	-0.85	1.16	1.35	1.58	-46.45	66.65	74.52	87.02	1.25	8.55	12.78	12.68	1.06	1.58	1.89	2.15
10	40	-0.60	0.90	1.07	1.21	-42.43	68.33	76.64	86.75	-0.60	11.35	16.91	16.71	1.06	1.58	1.89	2.15
11	40	-0.43	0.58	0.65	0.77	-38.53	64.73	73.12	81.84	-2.70	11.90	17.68	17.67	1.06	1.58	1.89	2.15
12	37	-0.17	0.34	0.38	0.41	-33.05	58.89	63.62	70.93	-1.86	14.73	21.93	21.71	1.11	1.68	1.96	2.23
13	35	-0.18	0.33	0.33	0.37	-29.03	51.54	55.12	61.60	-0.57	15.03	21.12	20.82	1.22	1.72	1.95	2.27
14	27	-0.31	0.35	0.32	0.44	-30.67	49.59	54.49	61.64	-3.44	14.17	20.81	20.71	1.01	1.54	2.08	2.28
15	18	-0.37	0.33	0.27	0.45	-32.89	47.71	56.35	63.88	-8.00	12.57	19.83	20.87	0.92	1.31	1.91	2.07

Table 8 METB3 results for VW in the MET error budget format where the statistics shown compare the RAOB-derived METB3s to the single climate-based METB3

		Vector Wind Speed (kn)			
Zone	Samples	Mean	MAE	SD	RMSE
0	40	-4.67	4.67	2.33	5.21
1	40	-5.53	5.53	3.06	6.31
2	40	-7.07	7.07	3.54	7.88
3	40	-8.18	8.18	3.45	8.86
4	40	-9.20	9.20	4.11	10.05
5	40	-10.62	10.62	4.51	11.52
6	40	-12.90	12.90	5.51	14.00
7	40	-15.70	15.70	6.37	16.91
8	40	-16.85	16.85	7.90	18.57
9	40	-18.26	18.26	10.11	20.81
10	40	-24.46	24.46	15.59	28.91
11	40	-26.53	26.53	15.15	30.46
12	37	-28.24	28.24	14.64	31.72
13	35	-26.89	26.89	12.48	29.57
14	27	-27.23	27.23	10.85	29.23
15	18	-28.12	28.12	9.74	29.67

The comparisons of METB3 values between the 40 YPG soundings and climate data presented in the MET error budget format suggest major differences between the climate-based mean profiles and the individual YPG soundings. The RMSE provides a measure of the total "error" relative to the climate mean profiles for the

spring season (March through May). The MAE also is an indicator of overall error. Chai and Draxler (2014) discuss the relative merits of RMSE and MAE and their use as indicators of error in numerical weather prediction models.

3. Conclusion

The data of this report indicate that individual soundings may vary widely from the climatological mean profiles. At times, the difference between a measured value (e.g., wind speed) at a given height and the climate mean exceeds 2 SDs. Consequently, climate mean values may significantly underestimate the effects of daily conditions at YPG or elsewhere and may lead to large discrepancies with respect to individual soundings. The data in the MET error budget format also indicate the large variation of individual MET soundings from the climate mean profiles. However, the variability of weather conditions at YPG is at most average for the northern hemisphere. Consequently, there are locations where 2 SDs from the mean profiles represent greater than to much greater than the MET parameter differences encountered at YPG. Nevertheless, if climate data are used to ascertain the large majority of MET values, then the mean + 2 SDs should be considered for wind speed and the mean ± 2 SDs for virtual temperature and pressure. The results presented herein are reasonable and not unexpected, and should be accounted for when setting up MET criteria.

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List of Symbols, Abbreviations, and Acronyms

ARDEC	US Army Research, Development and Engineering Center
MAE	mean absolute error
MET	meteorological
METB3	ballistic meteorological message for surface-to-surface fires
METCM	computer MET message
RMSE	root mean square error
RAOB	radiosonde observation sounding
SD	standard deviation
Tv	virtual temperature
VW	vector wind speed
YPG	Yuma Proving Ground

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